MECHANICAL, WEAR AND MACHINING STUDIES OF NANO BASALT POWDER AND SILICON CARBIDE REINFORCED ALUMINIUM BASED HYBRID COMPOSITES

A SYNOPSIS

Submitted by

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(Reg. No. 201414252)

in partial fulfilment for the award of the degree

of

DOCTOR OF PHILOSOPHY

DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL, AERO, AUTO AND CIVIL ENGINEERING

KALASALINGAM ACADEMY OF RESEARCH AND EDUCATION

(DEEMED TO BE UNIVERSITY)

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TAMIL NADU, INDIA.

JANUARY 2023

1. INTRODUCTION

The most significant developments in the history of materials are the creation of composite materials and the associated design and manufacturing processes. Additionally, solid materials and ceramics can now be used in three applications where monolithic versions are unsuitable due to their high strength scatter and weak resilience to mechanical and thermal shock thanks to composites technology. MMCs often have better strength and effect properties together with a high quality and high modulus arrangement. They are resilient to thermal system stress or temperature variations. Significant characteristics are high surface roughness and limited affectability to surface flaws. MMCs should make manufacturing, forming, and uniting with excellent surface completeness practicable [1]. Due to its low weight, high strength, workability, impressive corrosion resistance, castability, and great electrical and thermal conductivity, aluminium alloys are frequently used for a number of purposes in a variety of industries [2]. The bulk of aluminium alloys perform better than steel and other auxiliary metals in terms of quality to weight, but their wear, creep, and tiredness characteristics are often subpar.

The matrix alloy should only be chosen after carefully considering its chemical compatibility with reinforcements because it is the main component in MM [3]. Al is one of the best options for a matrix because of its superior mechanical properties, including its great corrosion resistance, high toughness, and low density. Al is also inexpensive when compared to other light-emitting substances. Therefore, advanced structural applications, strong wear resistance at high temperatures, and enhanced mechanical properties are important areas where aluminum-based MMCs have potential. It has been demonstrated that the ceramic particles for aluminium and aluminium alloy, which improve the mechanical property, are the most effective reinforcement materials. SiC is a strong reinforcement material that can be utilized for high temperature structural materials, creep, and corrosion resistance [4] [5]. In addition, silicon carbide was the first ceramic material utilized as reinforcement because of its superior resistance to high temperatures in usage for structural frameworks, as well as its effectiveness in fighting oxidation, corrosion, and creep [6].

Numerous fabrication techniques have been created as a result of considerable study on composite fabrication. One of the widely used liquid processing techniques to economically create AMCs in big quantities is stir casting. The stir casting method is easy, more adaptable, and appealing for processing AMCs because it theoretically permits using a traditional metal processing path [7]. Although it is difficult to fabricate AMCs without porosity, have good reinforcement wettability with the matrix, and distribute reinforcement materials uniformly throughout the matrix, defect-free composites can be created by applying the proper process parameter [8].

Wear is the progressive loss in the surface or subsurface caused by relative motion between the two contact surfaces. It is determined by dividing the weight loss by the volume decrease. Micro cracks and localized plastic deformation are examples of the wear damage [9]. The wear of material is influenced by the following single or combined factors: the applied load acting on the material surface, the rotational speed or velocity of the opposing surface, the type of material in contact, the surface roughness, and the presence or absence of lubricants at room temperature or above. The functionality of components is significantly impacted by the surface integrity of machined components. AWJMs have certain performance traits that make it possible to produce the appropriate level of quality. Additionally, AWJ machining outperforms other non-traditional machining methods in terms of performance. The main advantages of AWJ are the minimal cutting force applied to the parts and the absence of thermal flaws. Unlike AWJ machining, which uses water as a cutting tool to break the work material, standard machining procedures need that the cutting tool's hardness be greater than that of the work material in order to shear the material from the parent material [10].

2. LITERATURE REVIEW

By using a traditional stir casting process, Al7075 composites reinforced with boron carbide was created by Shaik et.al, [11]. The composite has excellent hardness, and the results showed that the boron carbide particles are dispersed uniformly. They discovered that the stir casting method is a successful method for enhancing the ballistic performance of metal matrix composites based on Al7075.

The impact of short basalt reinforcement on the mechanical characteristics of cast Aluminium alloy 7075 composites with short basalt content varying from 2.5 to 10 percent by weight in steps of 2.5 percent and manufactured using stir casting technology was employed. According to the study's findings, the ultimate tensile strength, hardness, compressive strength, and young's modulus all significantly rose as the amount of short basalt fibre in the material grew, while the ductility decreased. There has been a relative drop in the BHN with additional increases in basalt short fibre addition by Vannan and Vizhian [12]. Todic et. al., discovered the Basalt-polymer composite samples with varying ratios of basalts, polymeric matrices, and additives, as well as samples with diverse basalt particle composite grain sizes, were analysed. Results show the viability of the technical development process that would lead to basalt-polymer composite, a low-cost material with exceptional properties [13].

Bhushan et. al., analysed the stir casting process, Al 7075 and SiC particles are more wettable when Mg is added during stirring. With the use of SEM and XRD analyses, it was determined that the particles are uniformly dispersed and there is no secondary chemical reaction [14]. In order to reduce the SiC particle size, using a hot rolling process to create SiC particles reinforced aluminium (A356) metal matrix composite was employed. To validate the existence of foreign materials alloying with SiC particles, XRD method is performed. Taherzadeh et. al., concluded that as the reinforcement content climbed from 45% to 100%, so did the mechanical qualities [15]. By using SiC particles and stir-cast Al7075 alloy, the factors that affect the wear behaviour of these composite materials were investigated. Al7075 alloy reinforced with 7 weight percent SiC and 3 weight percent graphite particles was used to test the wear behaviour of hybrid composites. Kumar and Dhiman analysed using RSM, and it is discovered that the load and sliding speed are the two elements that have the greatest impact on the specific wear rate of composites [16].

Prabhakar et. al., analysed the sliding distance and composites' velocity are the next-largest influencing factors on wear rate after the load. The primary affecting factor is taking into account the coefficient of friction sliding distance, which is followed by the load and velocity of composites. The composites have mechanically mixed layers,delamination, worn surface analysis scratches,and shallow grooves [17].

The kerf taper caused by the retardation of the jet energy during machining has a significant impact on the operational precision of AWJ, which restricts the further application and advancement of AWJ technology. The findings demonstrate that cutting speed and material thickness have a significant impact on kerf taper, whereas water pressure and abrasive flow have less of an impact. The kerf taper will be reduced as the cutting speed is decreased, and it will become less pronounced as the material thickness increases analysed by Wang et. al ., [18]. Mohankumar and Kantha babu get the largest depth of cut in AWJM, MMCs out of aluminium 7075 reinforced with 5%, 10%, and 15% boron carbide was constructed. The findings showed that the unreinforced Al 7075 experienced a deeper cut than MMCs, which experienced a deeper cut at low abrasive mesh size, high water pressure, low traverse rate, and high abrasive flow rate [19].

3. RESEARCH OBJECTIVE

The present study on the development and investigation of properties of Al7075 alloy - basalt powder - SiC produced by this technique has the following objectives.

- To create hybrid composites using the stir casting method.
- To assess the novel hybrid composition's effects on qualities like wear, hardness, compressive strength, and tensile strength.
- To evaluate the wear resistance of an alloy made of Al7075, basalt powder (normal and nano form), and SiC with varying weight percentages of SiC and conventional and nano sized basalt powder.
- To assess the possibility of employing the nano basalt powder in combination with SiC in developing a hybrid metal matrix composite which can be more compatible in automobile, air craft industries etc.

4. RESEARCH PROBLEM

Using a novel technique, the creation of an aluminum hybrid composite material is being researched in order to suit the needs of advanced technical applications in the automotive and aerospace industries, where lightweight materials with high strength and resistance to friction are required. This work focuses on producing better aluminium composites with SiC and nano basalt as reinforcements.

4.1. Experimental Methodology

The material selection for producing secondary particles reinforced aluminium metal matrix composites and their suitability of Al7075 characterization was also discussed. Aluminium 7075 (Al7075) alloy is used as a matrix material in the current study work, and SiC and basalt powder in both their normal and nano forms are used as reinforcements in composites. The effectiveness of the bonding between the matrix and reinforcement is assessed using composite material characteristics. In order to achieve better outcomes with less reinforcement, nano composites (40 micron-sized basalt particles) are reinforced to the matrix, which can lower the cost of reinforcement particles. The various steps carried out in stir casting process of fabrication is presented in Figure 1.

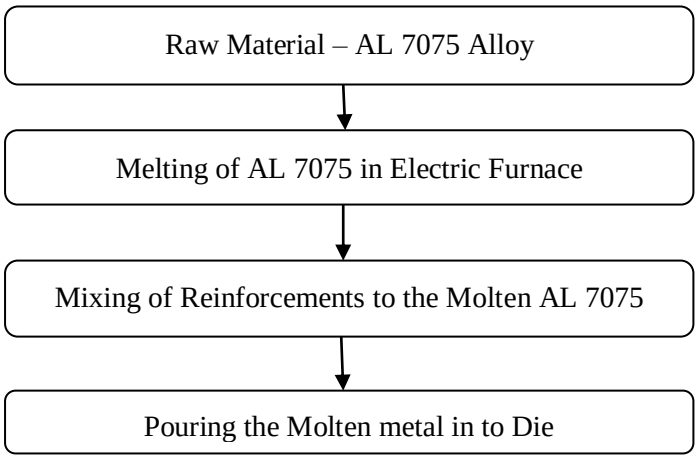
Raw Material – AL 7075 Alloy
Melting of AL 7075 in Electric Furnace
Mixing of Reinforcements to the Molten AL 7075
Pouring the Molten metal in to Die

FIGURE 1. Steps carried out in stir cast method

The experimental setup for the testing planned to conduct for determining the characterization of aluminium hybrid metal matrix composites such as mechanical properties, wear analysis and machinability characteristics through abrasive water jetting proves, surface roughness and kerf angle measurements respectively. Also worn surface analysis and wear debris analysis carried out for all Mono composites, Nano composites and Hybrid composites. This studies help the types wear analysis studied thoroughly.

The full experimental plan for the current study is shown as a flow chart in Figure 2.

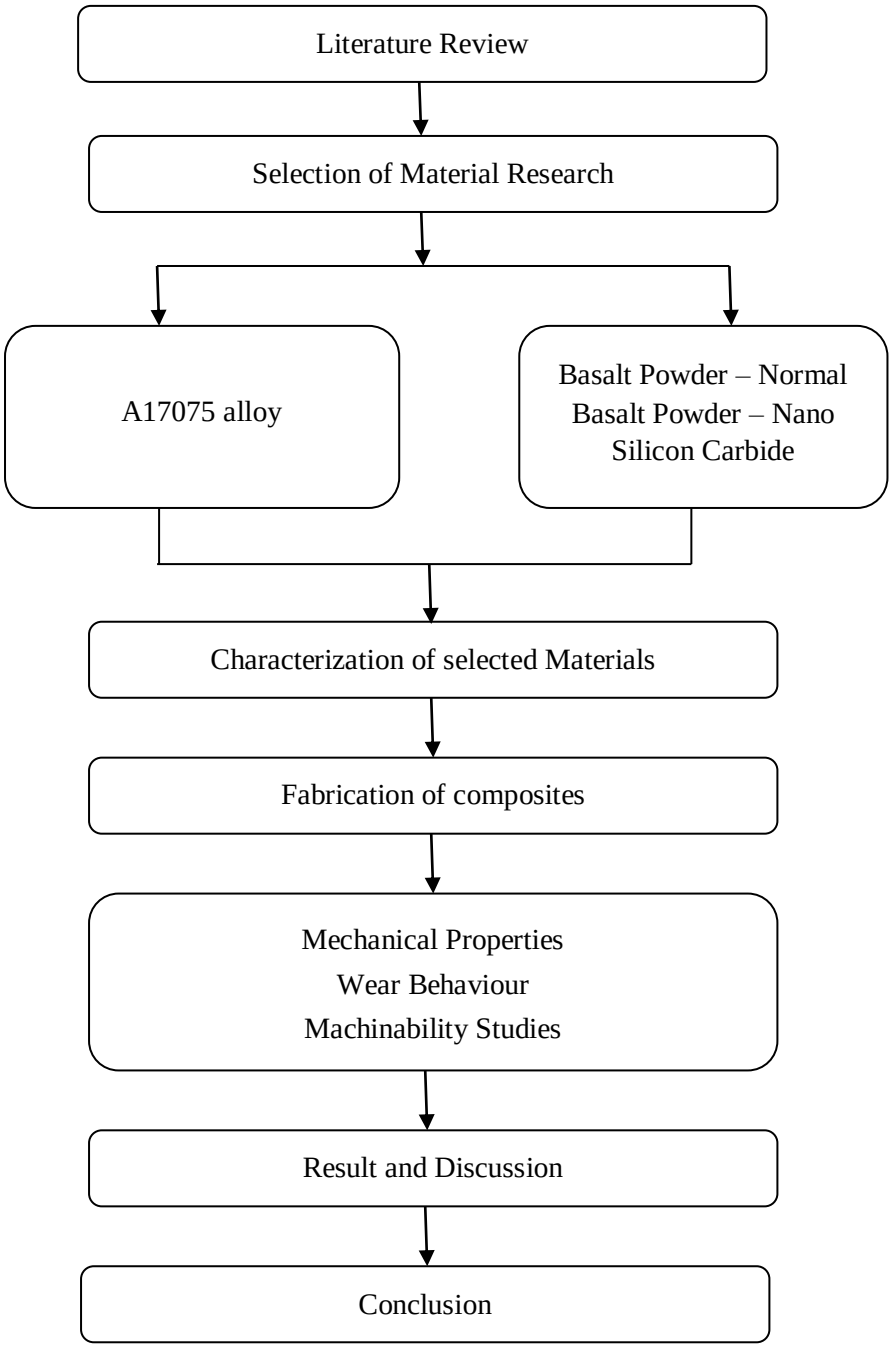

FIGURE 2. Flowchart methodology of proposed research work

5. EFFECT OF MONO BASALT PARTICLE IN COMPOSITES

The inclusion of basalt powder in powdered form as reinforcements in

developing stir casted hybrid Al7075 composites. Every characteristic of the newly developed Al7075/BsP composites are elaborately discussed and their results are presented in this chapter. The incorporation of BsP into the Al7075 matrix was carried out with a constant motorized stirring action, and molten metal was poured via the bottom of the crucible, preventing the production of inter metallic compounds and the presence of oxide layer inclusions in cast composites.

5.1 Mechanical properties for Mono composites

The majority of the uniformly scattered BsP particles in the aluminium matrix alloy are visible in SEM micrographs. Al7075 alloy hybrid composites with varied weight percent concentrations of BsP particle are investigated in terms of their theoretical and experimental densities. The results suggest that some voids exist in the manufactured BsP composites. Due to the existence of voids and pores, there is almost always a little discrepancy between the actual and theoretical density values. . Al 7075 matrix that has been cast with BsP particles has Vickers Hardness values that vary from 162 to 225 VHN. The composite with a larger volume % of reinforcement material, according to the microhardness data, has a greater microhardness. This might be as a result of the matrix material's presence of BsP particles in nano form and their uniform distribution.

The tensile strength enhancement of about 7.2%, 16.4%, 27.7%, 40.3% for Al/BsP composites at 2.5%, 5%, 7.5% and 10% reinforcement substitution levels. The percentage increase in the flexural strength exhibited was found to be 9.6%, 32.4%, 37.8%, 40.8% for Al/BsP composites respectively at various reinforcement substitution levels when compared with unreinforced Al7075 composite. Only somewhat significant improvements in the impact energy of composites were seen with reinforcing additions above 7.5% in Al/BsP composites. The slight improvement after 7.5% BsP may be attributable to the composites' micropores and the cracking that occurs at higher replacement levels in the interfaces between the reinforcement and matrix. The compressive strength of the composites under analysis shows an increasing trend with the increase in the weight percentage of the added reinforcements in the aluminium alloy matrix. The composite of aluminium Al7075 alloy reinforced with 10% reinforcement shows the highest compression strength of about 351 N/mm^2 for Al/BsP composites.

5.2 Wear studies for Mono composites

When the load was increased at this point a thin film is created between the wearing surfaces increasing the volumetric wear. While monitoring the aforementioned load, the coefficient of friction in the aluminium was discovered to be larger. The severity of plastic deformation can be described as increasing with applied load. It is possible to detect the growth of basalt particles on the counter surface as well as the transfer of aluminium matrix. The heat produced during the sliding wear assisted the formation of a protective oxide layer because the sliding distance is around 3000m. When the sliding speed was increased, the micromachining action of the reinforcing phases removed the protective layer, allowing the sliding surfaces to make an instant metal-metal contact. The sliding faces came into close contact, increasing the frictional coefficient. An increase in basalt weight percentage results in a high coefficient of friction and less wear loss. . When the weight percentage of the reinforcement was increased to 2.5%, plastic deformation emerged as a result of sliding wear that distorted the composite in its shape and structure. The creation of an adhesive layer and particle pullout on the worn surfaces were signs of adhesive wear at 5 weight percent of reinforcement material, although these signs would become more obvious as time went on. With more strengthening, the amount of wear debris generation likewise decreases. Because of the uniform distribution and robust interfacial connections between the particles and matrix, an increase in mass fraction resulted in a better strain hardening rate.

5.3 Machinaility studies for Mono composites

Lower amount of Ra and Kerf shows the high productivity of Abrasive Water Jetting Machine. Therefore, small the better are applied to calculate the optimum parameter sequence. Regardless of category of the performance characteristics, a smaller R_a value corresponds to a better performance. Material parameter leads the experiments, as it impact is high than all other machining parameters. During the cutting process the material removal is high during 2.5% of Basalt as it shows its effect high than other machining parameters. The acquired response graph shows the influence of various machining parameters and material parameter on the performance character R_a.

6. EFFECT OF NANO BASALT PARTICLE IN COMPOSITES

The inclusion of basalt powder in nano form into the Al7075 composites and their effect in enhancing the various characteristics of developed hybrid aluminium composites is discussed.

6.1 Mechanical properties for Nano Basalt particle in composites

The obtained micrographs clearly show that the matrix alloys and nBsP have excellent interfacial bonding. The resulting result shows a robust, reaction-free interface between the nBsP and Al7075 matrix that is clearly visible in Al7075 composites. This may be connected to the appropriate process parameters used to produce castings. It is evident that nBsP are homogeneously distributed throughout the matrix and are clustered. The presence of voids is compensated to a great extent in the nBsP composites. Due to gradual addition in the highly fluid metal liquid and appropriate stirring technique, the addition of different weight percent of nBsP particles in Al7075 disperse equally. The Al/nBsP composites without SiC content showed VHN values ranging from 196 to 256 respectively. The nBsP increases the substantial dislocation density while the composites are being processed, which provides increased resistance to plastic deformation and increased hardness. The tensile strength enhancement of about 18.1%, 24.9%, 34.5%, 46.4% for Al/nBsP composites respectively at 2.5%, 5%, 7.5% and 10% reinforcement substitution levels. The Al/nBsP composites showed an elongation varying from 11% to 8% respectively at all replacement levels. The results do, however, indicate that a rise in the weight percentage of the nano basalt powder particles was associated with the least amount of elongation reduction.

The percentage increase in the flexural strength exhibited was found to be 19.2%, 43.8%, 47.3% and 50.72% for Al/nBsP composites respectively at various reinforcement substitution levels when compared with unreinforced Al7075 composite. The substitution of nBsP improved the pores in aluminium composites than the normal basalt powder. It is noted that the energy values range from 1.34 to 2.13 Joule for Al/nBsP whereas the impact values was found to be less in all the unreinforced aluminium composites. According to obtained results, the maximum reinforcement level showed 3.13 times greater impact energy than the unreinforced

Al7075 composite for Al/nBsP composites respectively. The compressive strength ranges between 290 and 381 N/mm^2 for nBsP reinforced aluminium composites, whereas the highest strength enhancement of about 56% is achieved at 10% reinforcement level for Al/nBsP composites. This strength enhancement is followed by 7.5%, 5%, 2.5% of about 43%, 31%, 19% for nBsP reinforced composites respectively when compared with unreinforced Al7075 composite.

6.2 Wear studies for Nano composites

The frictional coefficient increased when the sliding faces came into close contact. A 10% weight increase favours delamination and the formation of wear debris even if it strengthens and stabilises the mechanical behaviour of the composite.

6.3 Machining studies for Nano composites

Based on the obtained results, the optimum parameter level sequence for obtained lower R_a is 220 bar pressure, 1 mm standoff distance, 20 mm/sec traverse speed, 0% basalt reinforcement in nano form.

7. EFFECT OF HYBRID COMPOSITES (NANO BASALT, SIC)

This chapter encompasses the comprehensive research work conducted on the potentials of using nano basalt powder coupled with silicon carbide as reinforcement in Al7075 matrix in the production of hybrid composites.

7.1 Mechanical properties for Nano basalt particle and Sic particle in composites (hybrid)

There is no evidence of cluster formation or agglomeration in nBsP/SiC composites, and the dispersion is uniform in all directions. These are the beneficial influencing elements that would improve the hybrid composite's mechanical and wear qualities. The density of casting samples demonstrates the value's progressive growth and the nBsP particles with SiC content increasing reinforcement in the alloy.

The reinforcing particles are distributed evenly throughout the matrix as the solidification period is lowered, leading to better grain size and a decreased risk of void formation. The superior hardness is visible in nBsP/SiC composites. In comparison to the Al7075 alloy with no reinforcement, the microhardness increased

by 76% for nBsP/SiC composites respectively at 10% substitution. The improved micro hardness is mainly due to the strong interfacial bonding and refined pore structure. The tensile strength enhancement of about 23.6%, 33.8%, 46%, 52.4% for Al/nBsP+SiC composites respectively at 2.5%, 5%, 7.5% and 10% reinforcement substitution levels. By transferring stress from the aluminium matrix to the reinforced particles, it improves the tensile strength primarily and decreases fracture of the composite material.

The percentage increase in the flexural strength exhibited was found to be 26.8%, 51.0%, 56.2%, 59.7% for Al/nBsP+SiC respectively at various reinforcement substitution levels when compared with unreinforced Al7075 composite. The greater flexural strength is mainly due to the strong and uniform binding of nBsP coupled with SiC which further helps in forming the dense structure of Al composite thereby filling the available pores in the composites. It is clearly observed that the nBsP with SiC composites showed greater impact energy above 10% reinforcement. The combined effect of nBsP and SiC made the aluminium composite denser which further helped in achieving greater impact strength. Additionally, it is noted that the energy values range from 1.51 to 2.59 Joule for Al/nBsP+SiC.

The greater enhancement in compressive strength is mainly due to the fine dispersion effect of nano basalt powder coupled with SiC into the Al7075 composite. The measured length seems to reduce certainly for increasing reinforcement levels which reflects the efficient workability of nBsP along with SiC content in aluminium composites. When basalt powder is added to Al7075 composites in nano form, followed by the addition of silicon carbide, this impact is significantly diminished.

7.2 Wear studies for hybrid composites

The best outcome was found at 4 m/s sliding velocity in all reinforcing types used in Al7075 composites when compared to other sliding velocities. Although the basalt powder in both normal and nano forms yielded a good machinability value for the developed composites, the superior machinability is achieved by combining nano basalt powder with SiC as reinforcement in Al7075 composites.

In a load range between 10 and 50 N, Figure 3. shows a decrease in the coefficient of friction as the weight fraction of reinforcement increases. When the load was increased at this point a thin film is created between the wearing surfaces increasing the volumetric wear. While monitoring the aforementioned load, the coefficient of friction in the aluminium was discovered to be larger. The severity of plastic deformation can be described as increasing with applied load.

At all load levels, least coefficient of friction is obtained for 10% reinforcement level followed by 7.5%, 5% and 2.5% and this trend is same in BsP, nBsP, nBsP/SiC composites. Applying the wear loss variation with variable applied force at a constant sliding distance of 3000m can be evident. With an increase in load, the wear loss of composites containing BsP, nBsP and nBsP/SiC gradually increased.

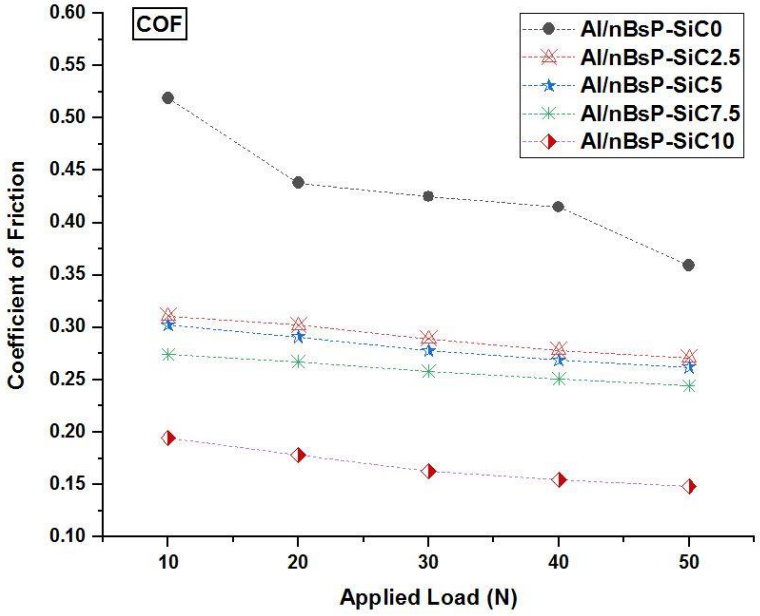

FIGURE 3. Co-efficient of Friction Vs Applied load of nBsP+SiC/Al7075 composite.

7.3 Machining studies for Hybrid composites

Based on the response table1 the optimum parameter level sequence for obtaining

Table 1. Experimental Results of Surface Roughness and Kerf Angle

Pressure (bar)	SOD (mm)	Traverse Speed (mm/s)	Basalt content (%)	Surface Roughness (R_a) in µm			Kerf angle		
				Al/ BsP	Al/ nBsP	Al/ nBsP-SiC	Al/ BsP	Al/ nBsP	Al/ nBsP-SiC
180	1	10	0	3.87	3.51	3.21	0.267	0.24	0.219
180	1.5	20	2.5	4.59	4.12	3.89	0.094	0.07	0.051
180	2	30	5	6.36	5.89	5.51	0.221	0.20	0.189
180	2.5	40	7.5	6.16	5.26	4.89	0.639	0.61	0.561
180	3	50	10	6.30	5.31	4.96	0.218	0.19	0.171
200	1	20	5	4.50	4.12	3.91	0.252	0.22	0.198
200	1.5	30	7.5	5.03	4.75	4.49	0.351	0.31	0.295
200	2	40	10	5.33	4.98	4.69	0.353	0.32	0.308
200	2.5	50	0	5.18	4.71	4.48	0.159	0.14	0.119
200	3	10	2.5	4.52	4.29	4.01	0.026	0.02	0.016
220	1	30	10	4.64	4.25	4.01	0.043	0.03	0.025
220	1.5	40	0	4.16	3.89	3.59	0.479	0.44	0.418
220	2	50	2.5	4.45	4.21	3.98	0.474	0.44	0.401
220	2.5	10	5	5.70	5.46	5.11	0.181	0.15	0.131
220	3	20	7.5	4.85	4.51	4.20	0.607	0.58	0.542
240	1	40	2.5	5.22	4.91	4.59	0.276	0.23	0.211
240	1.5	50	5	5.15	4.84	4.42	0.253	0.20	0.188
240	2	10	7.5	4.52	4.38	3.98	0.159	0.14	0.129
240	2.5	20	10	5.29	4.99	4.68	0.131	0.11	0.101
240	3	30	0	4.52	4.31	4.01	0.383	0.35	0.311
260	1	50	7.5	4.77	4.41	4.08	0.16	0.14	0.125
260	1.5	10	10	4.98	4.62	4.29	0.319	0.29	0.259
260	2	20	0	**3.73**	3.51	3.20	0.095	0.08	0.063
260	2.5	30	2.5	5.30	5.01	4.80	0.101	0.09	0.075

minimum Kerf and surface roughness is 220 bar pressure, 1 mm standoff distance, 10 mm/sec traverse speed, 2.5% basalt reinforcement.

8. CONCLUSION

The stronger binding of nBsP with SiC and subsequent formation of the dense structure of the Al composite, which serves to fill the accessible pores in the composites, are primarily responsible for the increased strength. The combined effects of nBsP and SiC caused the aluminium composite to become denser, which also helped to attain increased strength. Volumetric wear was demonstrated to decrease as the weight percent of reinforcement material increased due to the wear resistance offered by the action of basalt reinforcement in regular and nano form. The frictional coefficient increased when the sliding faces came into close contact. The high dislodgment density on the warped planes caused by the impact of the reinforcing particle produced grooves on the worn surfaces. A lower 'Ra number' indicates higher performance, regardless of the category of the performance criteria. While both the regular and nano forms of basalt powder produced high machinability values for the generated composites, the best machinability is obtained by mixing nano basalt powder with SiC as reinforcement in Al7075 composites. Al 7075 metal matrix composites reinforced with basalt powder, nano basalt powder, and silicon carbide have improved in all the ways mentioned above, demonstrating their suitability for usage in the structural components of the automotive and aerospace industries.

The references section includes about nearly more than one hundred and s***ome*** important references which have been clearly cited in the text.

9. ORGANIZATION OF THESIS

The thesis is organized in seven chapters.

Chapter 1: This chapter illustrate about the types of composites, processing of composites, machining of composites and optimization techniques are briefly explained.

Chapter 2: This chapter presents the literature survey conducted on production of Aluminium MMCs, machining of Aluminium MMCs and the optimization techniques adopted. This chapter summarizes the earlier works carried out by various researchers and identifies the research gaps.

Chapter 3: This chapter explains about the candidate material and process parameters for the experimentations. Also, explains the methodology of experimentation and its equipment's. The measurement and characterization methods and procedure for investigation also discussed in detail.

Chapter 4: In this chapter, briefly describe the manufacture of mono composites and the mechanical properties that were examined and plotted. Also, include information on the machining and wear studies for the mono composite.

Chapter 5: In this chapter, briefly explain about the Nano basalt particle composites preparation and machining studies. The mechanism of wear studies and mechanical properties described.

Chapter 6: In this chapter, briefly explain about the Nano basalt particle with SIC hybrid composites preparation and mechanical properties studied. By using abrasive water jet machining, surface roughness and kerf angle analysed.

Chapter 7: Based on the results and discussion, the conclusions are made for the research work and the future scopes of the work were discussed in this chapter.

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LIST OF PUBLICATIONS

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